Insertion of the denture during MR imaging reduces motion artifact of the tongue images

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Contents

Ⅰ. Abstract

Clear magnetic resonance imaging (MRI) is required to diagnose tongue cancer. However, tongue movement with unstable swallowing cause artifacts on MRI. This tongue movement may be associated with loss of occlusal support. The purpose of this study was to examine the reduction of motion artifacts in edentulous or those without occlusal support.

Research 1 compared the manifest of artifacts under the tongue at rest and in motion with dentulous subjects (5 males and 5 females; age 31.50 ± 8.38 years) with occlusal support, as by qualitatively from the image and by quantitatively by using luminance standard deviation (LSD). MRI was conducted with the tongue at resting position, followed by the tongue in motion. LSD was measured in the regions of interest (ROI) in the axial and sagittal planes. As the results, there was no apparent tongue motion artifact of the MR image at rest, but the lack of clarity of the MR images was prominent when the tongue was in motion. In axial plane, the LSD was significantly higher with the tongue at rest than the tongue in motion ($p = 0.004$), and there were no differences of LSD between the positions of the four ROIs ($p = 0.16$). In sagittal, the LSD was significantly higher with the tongue at rest than the tongue in motion at both positions of the two ROIs (ROI-A: $p = 0.002$, ROI-P: $p = 0.006$). The results showed that evaluation of the motion artifacts occurrence is possible by using the LSD.

Research 2 aimed to clarify whether motion artifacts can be mitigated by denture insertion during MRI examination in patients without occlusal support by introducing the tongue stability, form, and position. Quantitative assessment was carried out by using the LSD as the motion artifact evaluation. Subjects were ten patients without occlusal support (6 males and 4 females; age 73.20 ± 10.12 years). MRI was conducted with dentures worn (DW), followed by a removal of the dentures (NDW). LSD was measured in ROI in the axial and sagittal planes. And the position of the base of the tongue (TB), the position of the apex of tongue (TA), and tongue's long diameter (TLD) was measured. As a result, motion artifacts in MR images with DW largely absent. And the running of the genioglossus muscle and regions of the superior longitudinal, inferior longitudinal, geniohyoid and mylohyoid muscles were clearly observed. In contrast, with NDW, there was ambiguity in the tongue's contour due to motion artifact. LSD was significantly higher with DW than NDW (axial: $p = 0.047$, sagittal: $p = 0.02$). There were no significant differences of TB between DW and NDW ($p = 0.78$). TA and TLD were significantly greater with DW compared with NDW (TA: $p = 0.007$, TLD: $p = 0.001$).

The results suggest that motion artifact(s) appeared with these movements. Furthermore, tongue and mandibular movement can be inhibited by DW, and the reduction of motion artifact is possible, and that edentulous patients without occlusal support may alter the normal/natural form of the tongue when supine and undergoing MRI examination, which may impair accurate localization of lesions such as cancer.

Ⅱ. Introduction

Japan has become a globally unique super-aged society, and this trend is expected to continue into the future[1]. Morbidity rates of malignant neoplasms, heart disease, and cerebrovascular disease are among the leading causes of death in this country[1]. Tongue cancer and temporomandibular joint disease are also expected to increase according to this demographic trend. Magnetic resonance imaging (MRI) is an efficient method of detecting and diagnosing these diseases, especially not only the primary tumor in tongue cancer but also lymph node metastasis[2-4].

The MR image has to be clear, but MR image is indistinct, or distortion is caused, and interpretation may be disturbed, and one of the factors includes artifact[5]. In that, motion artifact(s) created by patient movement is more difficult to control[6].

The majority of patients requiring MRI for the oral-related disease are elderly and, in general, have fewer remaining teeth; thus, the prevalence of edentulous individuals with or without occlusal support tend to be high. The report indicates that the movement of the mandible and tongue during swallowing are more prominent in edentulous subjects than in healthy dentate subjects[7-9]. The tongue/mandible motion causes motion artifacts on MRI. Also, deviation of the tongue due to tooth defect may cause tongue motion artifact.

In the conventional laboratory method, the patient is instructed to remain as still as possible. However, this is mostly patient dependent, and inhibition of movement varies with each patient. It is also considered that it is not easy to suppress the movement. These tongue motion artifact(s) can limit the acquisition of clear margins between tongue squamous cell carcinoma and extrinsic muscles[10]. Thus, diagnosis of the stage classification of the malignant tumor will be limited and affect treatment decisions of operation. Therefore, it is necessary to suppress deviation caused by movement of the mandible and tongue during the examination and to minimize the development of motion artifacts.

Frequent dental interventions in these individuals include fabrication and delivery of removable prostheses to recover masticatory function and esthetics. These interventions are one of the important roles of clinical dentistry and frequently done as a dental treatment. By wearing a removable prosthesis which assumes a denture a representative during MRI, the position of the lower jaw and the tongue is expected to be stabilized when compared with non-denture wear[7, 11]. This is achieved by mandibular stability, occlusal support, fulfilling denture space by adequate denture, and achieving "tongue-palate contact" during swallowing[8, 9, 11]. The reduction of the motion artifact may be obtained by the stability of tongue and the mandibular position to insert the denture as an important prosthodontic treatment.

As a general rule when individuals wearing denture prostheses require MRI of the head and neck region, the examiner asks for their removal because the dental alloy used in removable appliances cause metallic artifacts, and may generate heat and, possibly, dislodgement of the prostheses during imaging[12]. Therefore, it is necessary to show the relationship between mandibular position and tongue stability and motion artifacts due to wearing of a denture. Several reports assessed the motion artifacts related to respiration during abdominal imaging and blood flow during head imaging[13-18]. However, the evaluation of motion artifacts due to tongue movement has not been thoroughly investigated.

An objective assessment criterion is needed to evaluate the degree of motion artifacts on MR images with tongue and mandible movements. Luminance is used as an objective index of images and used to evaluate the knee symptoms[19]. In the photology, luminance standard deviation (LSD) decreases when the contrast is low, that is, the LSD become smaller when the portrait photo image blurring is rise[20]. The LSD can be used as an assessed value of the contrast on MR images and as an estimated value of noise[21-23].

The purpose of this study, therefore, was to investigate the effect of denture wearing on the reduction of motion artifacts of the tongue in edentulous individuals without occlusal support. In Research 1, the objectives were to investigate the concurrent validity of LSD for the assessment of motion artifacts associated with tongue motion by comparing the levels of artifacts of dentulous subjects with the tongue at rest and in motion. And in Research 2, the effect of denture wearing during MRI on the stability of the tongue's form and a decrease of motion artifact were evaluated.

Ⅲ-1. [Research 1] Investigation of the evaluation method of the motion artifact in the dentulous

1. Methods

1) Subjects

The subjects were ten patients (5 men and 5 women; average age: 31.50 ± 8.38 years; an average number of remaining teeth: 27.50 ± 1.27) who had received treatment at the Kita Kashiwa Rehabilitation General Hospital (Kashiwa-Shi, Chiba, Japan). Inclusion criteria were as follows: (i) dentulous subjects with occlusal support, (ii) no consecutive tooth loss of more than two teeth, (iii) no soft tissue disease in the oral cavity.

Exclusion criteria were as follows; subjects with (i) involuntary movement during MR imaging in the oral and maxillofacial regions and any other part of the body, (ii) absolute and/or principle contraindications of MR imaging, such as a pacemaker, a cochlear implant, or claustrophobia, (iii) ferromagnetic metal in the oral cavity, (iv) swallowing disorder caused by a 10-mm increase or decrease in the occlusal vertical dimension compared to the adequate position.

Written informed consent was obtained from all participants after receiving a written form and explanation of the purpose and methods of the study. The institutional review board approved the study protocol (Ethical Committee of Nihon University School of Dentistry at Matsudo, approval no. EC 16-15-019-1). The protocol was also registered to a clinical trial registry database (ClinicalTrials.gov, NCT03018158).

2) MRI

The MR images were obtained using 1.5-T scanners (Vantage Titan, Toshiba Medical Systems, Otawara, Japan) with a head coil. All images were obtained in both the axial and sagittal planes. The measurements of the MR images were performed on T2-weighted images with fat saturation (T2WI+FS) due to their good depictions of tumors[24, 25].

Axial imaging was performed with the following parameters: repetition time (TR) = 6,500 ms; echo time (TE) = 100 ms; number of excitations (NEX) = 1; slice thickness = 4.0 mm; gap = 0.8. Sagittal imaging was performed with the following parameters: TR = 6,500 ms; TE = 100 ms; NEX = 1; slice thickness = 5.0 mm; gap = 0.1.

3) MRI examinations

Before the MRI, an examiner observed the occlusal status of the patient and identified the stability and reproducibility of their intercuspal position. In advance of MRI, every subject practiced their tongue movement under the guidance of a clinician, and reproducibility of the movement was confirmed. During the MRI, the participants were asked to maintain the intercuspal position with the mouth closed. Imaging was conducted with the tongue in the resting position, followed by movement of the tongue to the right and left within the oral cavity at the pace of one movement per one second.

4) Image analysis

All images were analyzed using ROI tools of software version 2.31 on a console of MRI device. The region of interest (ROI) of each image was a circle: 20 mm in diameter (Fig. 1, 2). The settings of the ROIs were decided by consensus among the three examiners: a radiological technologist, and two dentists. And the ROIs were positioned in the axial plane with a maximum tongue area and the median sagittal plane on the T2WI+FS under tongue movement and resting conditions. The LSD was calculated as a standard deviation by measuring the luminance of 560 points in the ROI. Also, to examine the effect of the tongue thickness to the LSD, the thickness of the tongue muscle was measured[26] in the sagittal plane under tongue resting conditions and analyzed (Fig. 3).

5) Statistical analysis

A two-way repeated measures ANOVA was used to analyze the effect of tongue movement and the ROI position on the LSD in the axial plane. Paired t-test was used to analyze the difference between the tongue in motion and at rest on the LSD; both at sagittal ROI-A and P respectively. Single linear regression analysis was used to analyze the effect of the tongue thickness on the LSD. SPSS Statistics for Windows, version 21.0 (IBM Corp., Armonk, NY, USA) was used for analysis, with a significance level of 5%.

2. Results

1) Image findings

The MR images of the tongue at rest and in motion are shown in Fig. 4. No noticeable tongue motion artifacts of the MR image at rest were observed in either the axial or the sagittal planes (Fig. 4-A). The lack of clarity of the MR images was prominent when the tongue was in motion. The intrinsic muscle of the tongue in the axial plane, and the anatomical forms at the base of the tongue and the oropharynx in the sagittal plane MR images were unclear (Fig. 4-B).

2) LSD

In the axial plane, the LSD was significantly higher with the tongue at rest than in motion ($p = 0.004$). There were no significant differences between the four ROIs positions ($p = 0.16$). No interaction with the tongue condition and the ROI position were detected ($p = 0.07$) (Fig. 5). In the sagittal plane, the LSD was significantly higher with the tongue at rest than in motion at ROI-A ($p = 0.002$) and ROI-P ($p = 0.006$) (Fig. 6). Single regression analysis showed that the thickness of the tongue had no influence on LSD both with axial ($p = 0.26$) and sagittal plane ($p = 0.74$).

Ⅲ-2. [Research 2] Investigation of the motion artifact reduction by the denture wearing

1. Methods

1) Subjects

Subjects included ten patients (6 men, 4 women; mean age 73.20 ± 10.12 years; mean number of remaining teeth: 2.60 ± 3.86) who received treatment at the Kita Kashiwa Rehabilitation General Hospital. Inclusion criteria were as follows: (i) subjects in Eichner Index group C, (ii) subjects wearing dentures, (iii) no soft tissue disease in the oral cavity. Exclusion criteria were similar to research 1.

Informed written consent was obtained from all participants after they received a written form explaining the purpose and methods of the study and explained by the examiner. The study protocol was approved by the Institutional Review Board (Ethical Committee of Nihon University School of Dentistry at Matsudo, approval no. EC 16-15-019-1). The protocol was also registered to a clinical trial registry database (ClinicalTrials.gov, NCT03018158).

In the Eichner classification, each posterior contact area, including both the premolar and molar regions, are counted as one zone, yielding a total of four supporting zones[27)]. In this study, group C, who have no occlusal contact were included. Group C is allocated into following three subgroups; group C1 has at least one tooth in both the mandible and maxilla without any occlusal contact; group C2 has at least one tooth in either the mandible or maxilla and group C3 is fully edentulous in both arches.

2) MRI

The MRI scanner, the imaging sequence and parameters to use are similar to research 1.

3) MRI examinations

Subjects underwent imaging while wearing their denture, followed by removal of the denture.

(1) Denture wearing (DW)

Subjects were imaged in occlusion with their dentures worn. The denture was determined according to the occlusal vertical dimension determined by maxillomandibular registration in the physiological rest position. In cases of partial dentures that contained ferromagnetic metal, for which the development of the metal artifact was predicted, a non-metal copy denture was fabricated beforehand and worn during the MRI examination. A dentist confirmed occlusal stability and reproducibility of the denture worn for imaging before MRI and made adjustments as needed. The patient was instructed to maintain mandibular position and the tongue stationary during imaging.

(2) Denture non-wearing (NDW)

After imaging with the denture worn was completed, the denture was removed with the head in a fixed position, and MRI was performed with the mandible in the rest position. A dentist confirmed the rest position of the mandible in subjects before imaging, and the subjects practiced reproducing the position spontaneously. Patients were instructed to maintain the practiced mandibular position and to keep the tongue stationary during imaging.

4) Image analysis

All images were analyzed using same software as research 1.

(1) Image findings

The clearness of contour of the tongue, running of the tongue muscle, the clearness of the oropharyngeal region, the lips morphology, and mentum clearness were observed. The image of DW and NDW were evaluated subjectively by two oral surgeons to confirm the images of DW were clear and suitable for clinical diagnosis than that of NDW. The evaluators classified all blinded image into DW or NDW into "clear" or "unclear".

(2) LSD

A circular ROI, 20 mm in diameter, was placed on each image (Fig. 7). The ROIs were confirmed by consensus among the three examiners, i.e., a radiological technologist and two dentists. And the ROIs were positioned in the axial and sagittal planes on the T2WI+FS under the two oral conditions, i.e., DW and NDW. Slice planes to be used and calculation method of LSD were similar to research 1.

(3) Tongue form and position

The position of the base of tongue (TB) was measured according to the methods described by Fujiki et al.[26] and Gokce et al.[28] in the sagittal plane (Fig. 8). The position of the apex of tongue (TA) and the tongue's long diameter (TLD) were measured according to methods described by Fujiki et al.[26] in the sagittal plane (Fig. 8). Each form and position evaluation was performed by measurement of the distance that was parallel to a palatal plane[26, 29]. The palatal plane is an anatomical standard plane in the midsagittal slice, and can be drawn based on a line from the anterior nasal spine to the posterior nasal spine (PNS)[30]. The positions of TB and TA were evaluated by measuring the distance from a certain place; when TB and TA are located posterior, the distance becomes shorter[26, 28]. Measurements were confirmed by consensus among three examiners, i.e., the radiological technologists, and two dentists.

5) Statistical analysis

The chi-square test was performed to analyze the ratio at which the DW image was judged to be the clear image by the subjective evaluation. The paired t-test was performed to analyze the influence of denture wearing on motion artifacts caused by the tongue, and LSDs of denture wearing and non-wearing were compared. Additionally, the paired t-test was used to analyze the position of TB and TA, and TLD in the sagittal plane, as influenced by denture wearing on the stability of tongue position. SPSS Statistics for Windows, version 21.0 (IBM Corp., Armonk, NY, USA) was used for analysis, with a significance level of 5%.

2. Results

1) Image findings

MRI findings under each measurement condition are presented in Figure 9. Motion artifacts in MR axial plane images with DW mostly absent. Imaging recognized the contours of the tongue, the running of the genioglossus muscle, and the tongue septum. In contrast, MR images in NDW in the axial plane, compared with DW, revealed a shortened TLD, with ambiguity in the tongue's contour and the running of the genioglossus muscle due to motion artifact. Moreover, the border of the pharynx and tongue was also unclear.

Motion artifacts in MR images in DW in the sagittal plane were mostly absent. The tongue contour, the running of the genioglossus muscle, and regions of the superior longitudinal, inferior longitudinal, geniohyoid, and mylohyoid muscles were recognized clearly.

In contrast, MR images in NDW in the sagittal plane, compared with DW, depicted the tongue and mentum to be located backward, and the lips were recessed. Furthermore, there was ambiguity in the tongue's contour and the running of the genioglossus muscle, and regions of the superior longitudinal, inferior longitudinal, geniohyoid and mylohyoid muscles.

Also, DW significantly affects the judgment of artifact occurrence by subjective evaluation ($p = 0.00$).

2) LSD

LSD was significantly higher with DW than NDW in axial ($p = 0.047$) and sagittal plane ($p = 0.02$) images, (Fig. 10).

3) Tongue form and position

In sagittal plane images, there were no significant differences between DW and NDW ($p = 0.78$) about the distance from the back wall of the pharynx to tongue's posterior point (Fig. 11). The shortest distance from the line crossing at a right angle to the palatal plane through the PNS to the apex of tongue was significantly higher with DW than NDW ($p = 0.007$). TLD was significantly higher with DW compared with NDW ($p = 0.001$) (Fig. 11).

Ⅳ. Discussion

This study was conducted to consider the influence of wearing of denture on motion artifact for edentulous patients and individuals without occlusal support. The objectives of research 1 as pilot study were to investigate the concurrent validity of LSD for the assessment of motion artifacts associated with tongue motion by comparing the levels of artifacts of dentulous subjects with the tongue at rest and in motion.

1) The concurrent validity of LSD for the assessment of motion artifacts (Research 1)

The results showed that motion artifacts occurred and MR image was unclear when the tongue was in motion. And the LSD values were significantly smaller when the tongue was in motion compared to at rest, in both axial and sagittal planes. Luminance is used as an objective index of images, used to evaluate the knee symptoms and a change of the luminance in MR image[19].

Luminance standard deviation value is used as an objective index of the MR image as a definition of contrast and as an estimated value of noise[21-23].

The feature is that as blurring of the image increases, the contrast is reduced and the luminance standard deviation decreases[10, 14]. In the MR image, the contrast is reduced in images blurred by the motion artifact. The results showed that the LSD was significantly smaller in MR images with motion artifacts. Therefore, it is possible to objectively evaluate the occurrence of motion artifacts using the LSD.

2) Investigation of the LSD measurement position (Research 1)

The results showed that there were no significant differences among the regions; indicating that the LSD is an effective evaluation of motion artifacts in any region of the tongue. Also in the sagittal plane, even at different regions of the tongue, LSD significantly decreased by tongue movement. In the axial and sagittal planes, the LSD of the MR images with motion artifacts converged to the approximate value regardless of the regions with different contrast intensities in the normal image.

3) Influence of thickness of tongue muscle to LSD (Research 1)

The effect of individual differences in the thickness of the tongue muscle on LSD was examined. Results showed no significant effect, and it showed that LSD could be used for comparison of motion artifact regardless of the thickness of the tongue muscle.

From these results, it is suggested that the measurement of LSD is valid as the evaluation of motion artifact. Also, it was suggested that motion artifact could be evaluated by LSD even measured any position of the tongue.

Research 1 showed the concurrent validity of objective evaluation of motion artifacts using LSD. However, the problem is the movement of the tongue and mandibular of edentulous patients and individuals without occlusal support. In research 2, whether motion artifacts can be reduced by denture wearing during MR imaging for these patients was examined.

4) Influence on LSD by denture wearing (Research 2)

LSD was significantly greater with DW than with NDW. High LSD indicates high contrast and clear imaging[10, 21-23]. The motion artifacts by the tongue and mandible movements may be suppressed by wearing the denture. And subjective evaluation supports the validity of the objective evaluation of LSD because DW significantly affected the judgment of clarity of the image.

MR images with motion artifacts lead to ambiguity caused by movement of the patient (i.e., a motion artifact in the tongue region is caused by tongue and mandibular movement). It has been reported that edentulous patients and those without occlusal support exhibit this type of movement when swallowing, and more so than dentulous individuals[7, 9]. By placing their tongues between the edentulous alveolar ridges to form an anterior seal, the tongue body is significantly shifted forward more than dentulous individuals during swallowing maneuvers[8]. It has also been reported that there are many such tongue tip types in edentulous patients in

NDW[7]. In these individuals, the apex of tongue motion is frequently altered in various directions, and moves restlessly until finally anchored against the palate. Even after anchoring, the apex of tongue continues to move slightly around the anchor point[7]. Additionally, the antedisplacement of TB is large in NDW[8, 9, 11]. Mandibular movement in NDW is rotated forward and upward in swallowing because stabilization by the occlusion of the posterior teeth or dental prosthesis is lost[8, 11]. These movements are a major reason why it is difficult to suppress tongue motion artifacts during MRI examination.

However, there are reports that it is possible to suppress the movement of the tongue and mandible during swallowing in edentulous patients and those without occlusal support by DW. Movement of the tongue can be suppressed by forwarding blockade and by stabilizing tongue-palate contact with a denture[11]; movement of the mandible can further prevent deviation by supplementing occlusal support[11].

In other words, in edentulous patients and those without occlusal support, the results suggest that motion artifact(s) on the MR images appeared with these movements. Furthermore, tongue and mandibular movement can be inhibited by DW, and the reduction of motion artifact is possible.

5) Influence on tongue form and position by the denture wearing (Research 2)

The influence on the stability of form of the tongue by denture wearing for edentulous patients and those without occlusal support on MR image diagnosis in addition to the movement of the tongue was examined. There was no significant difference in the position of TB between DW and NDW. However, the position of TA was significantly shifted posteriorly in DW compared with NDW, and the tongue body was also significantly shortened.

Distance from the most extreme posterior of TB to the pharynx posterior wall in DW was measured, and there were subjects with a shortened distance and subjects with increased distance.

When edentulous individuals perform swallowing in NDW, the anterior upper shift in the mandibular position pulls the anatomically continuous hyoid bone and TB in an anterosuperior direction through the genioglossus muscle[8, 9, 11]. Additionally, one study reported that the physical thickness of the denture base and artificial teeth shift the tongue posteriorly with DW[28]. For these reasons, there were some subjects in whom TB was located posteriorly with DW compared with NDW.

However, MRI is usually performed with the patient supine, TB may sink because of gravity, leading to restriction of the oropharynx[31]. Due to muscular strength, subjects affected by gravity were believed to have recovered their tongue in the anterior direction by tongue-palate contact as an index point of tongue position through DW[11]. In other words, in patients with edentulous chins and those who lost occlusal support, DW has conflicting influences on posterior deviation and forward movement of TB.

However, in the future, it is necessary to examine the change of the position of TB between the sitting and the supine position in each subject, and it is essential to investigate whether movements of TB are influenced by gravity or by DW. And it is necessary to examine the influence of the thickness of the denture base and position of arrangement of the artificial teeth on the TB posteriorly slide.

Also, the position of TA was significantly shifted posteriorly compared with NDW, and the tongue body was also significantly shortened. The apex of tongue, which is anatomically not directly connected to other parts of the mouth, is comparatively morphologically and positionally free. In the supine position, in particular, it is believed that the apex of tongue is shifted posteriorly under the influence of gravity and, loses an indicator due to loss of contact between the tongue and palate[11)]. Furthermore, in the supine position, it has been reported that the tongue's form shortens and lengthens back and forth, and the diameter increases[32)], which is consistent with observations in this study. Because the apex of tongue moves posteriorly, tongue as a whole shows shortened appearance.

These results suggest that edentulous patients and those without occlusal support may alter the normal/natural form of the tongue when supine and undergo MRI examination, which may impair accurate localization of lesions such as cancer.

The results of these two pieces of research suggested that denture wearing during MR imaging in edentulous patients and those without occlusal support would contribute to accurate MR imaging of the tongue, because a motion artifact is reduced by a tongue and mandibular movement being inhibited and restores tongue's form at normal.

This study aimed to detect whether the denture wears decrease the MRI motion artifact in edentulous patients and those without occlusal support. In the following investigation, whether this reduction is worthwhile for the diagnosis has to be clarified. Also, from a prosthetic point of view, it has to make clear the reduction is also valid for first-time denture user. For the patient who has been edentulous and had no denture experience, the development of the appliance alternative to denture should take into consideration.

Ⅴ. Conclusions

The results of the two researches revealed the following.

1. It was suggested that luminance standard deviation (LSD) could efficiently be used regardless of the measurement position of the tongue and the thickness of the tongue muscle as evaluation of motion artifact.
2. It was suggested that denture insertion during MR imaging in edentulous patients and those

without occlusal support would contribute to accurate MR imaging of the tongue because a motion artifact is reduced by a tongue and mandibular movement being inhibited and restores tongue's form at normal.

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Ⅶ. Figures

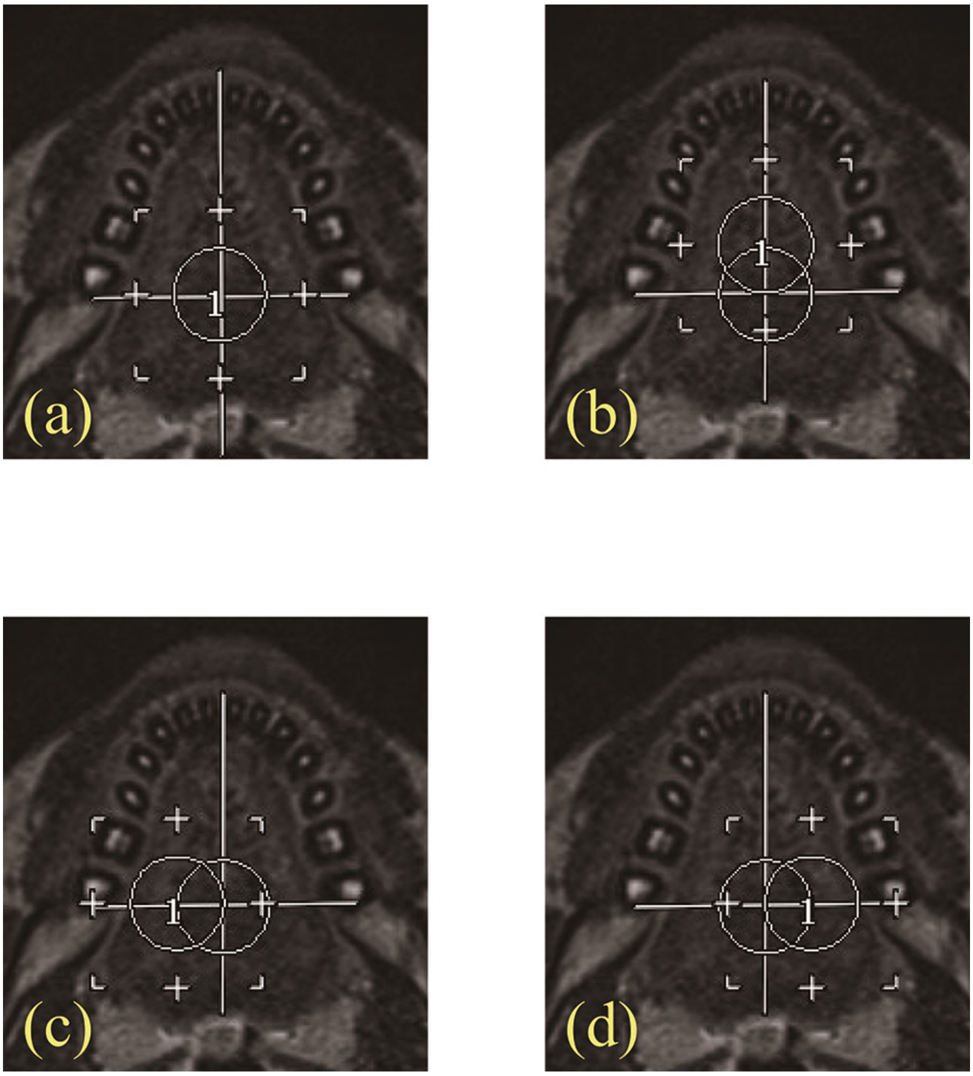

Fig. 1　ROI placement in the axial plane image with a maximum tongue area

The ROIs were circles 20 mm in diameter; the center of the circle was placed at the point of intersection of: (a) the median line and the line that linked the right and left distal sides of the mandibular second molar (ROI-C), (b) the median line and the front margin of the ROI-C (ROI-F), (c) the left margin of the ROI-C and the line that linked the right and left distal sides of the mandibular second molar (ROI-L), and (d) the right margin of the ROI-C and the line that linked the right and left distal sides of the mandibular second molar(ROI-R).

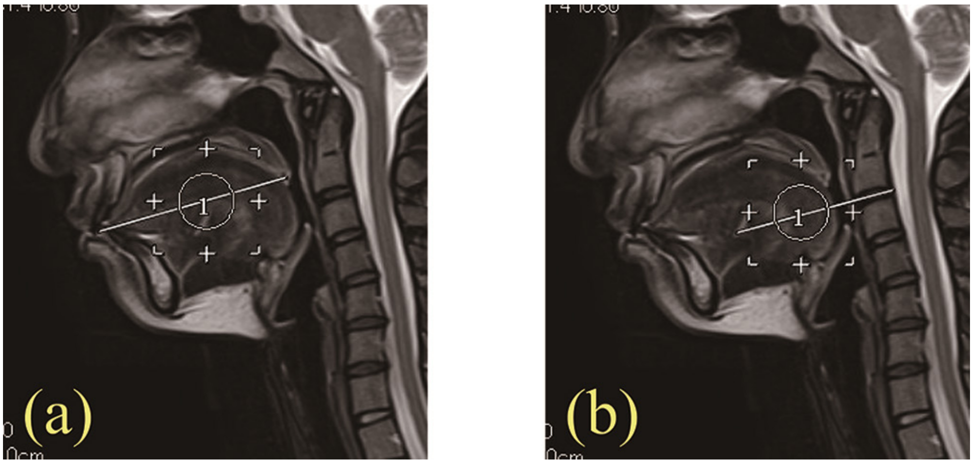

Fig. 2　ROI placement in the median sagittal plane image

The ROIs were circles 20 mm in diameter; the center of the circle was placed as follows: (a) on the line that linked the incisal of the anterior of the mandible and the most posterior point of the soft palate; the ROI included the section of the tongue with maximal thickness (ROI-A), and (b) on the extension line of inferior margin of the axis body of the vertebra; the ROI's posterior margin was at posterior margin of the base of the tongue (ROI-P).

Fig. 3　The thickness of tongue muscles

The thickness of tongue muscles measurement was performed by measuring the vertical linear distance to the palatal plane, which is an anatomical standard plane in the midsagittal slice, and is drawn based on a line from the anterior nasal spine to the posterior nasal spine (PNS). The thickness is measured from superior margin of the tongue to inferior margin of the genioglossus muscle on a perpendicular line starting from PNS.

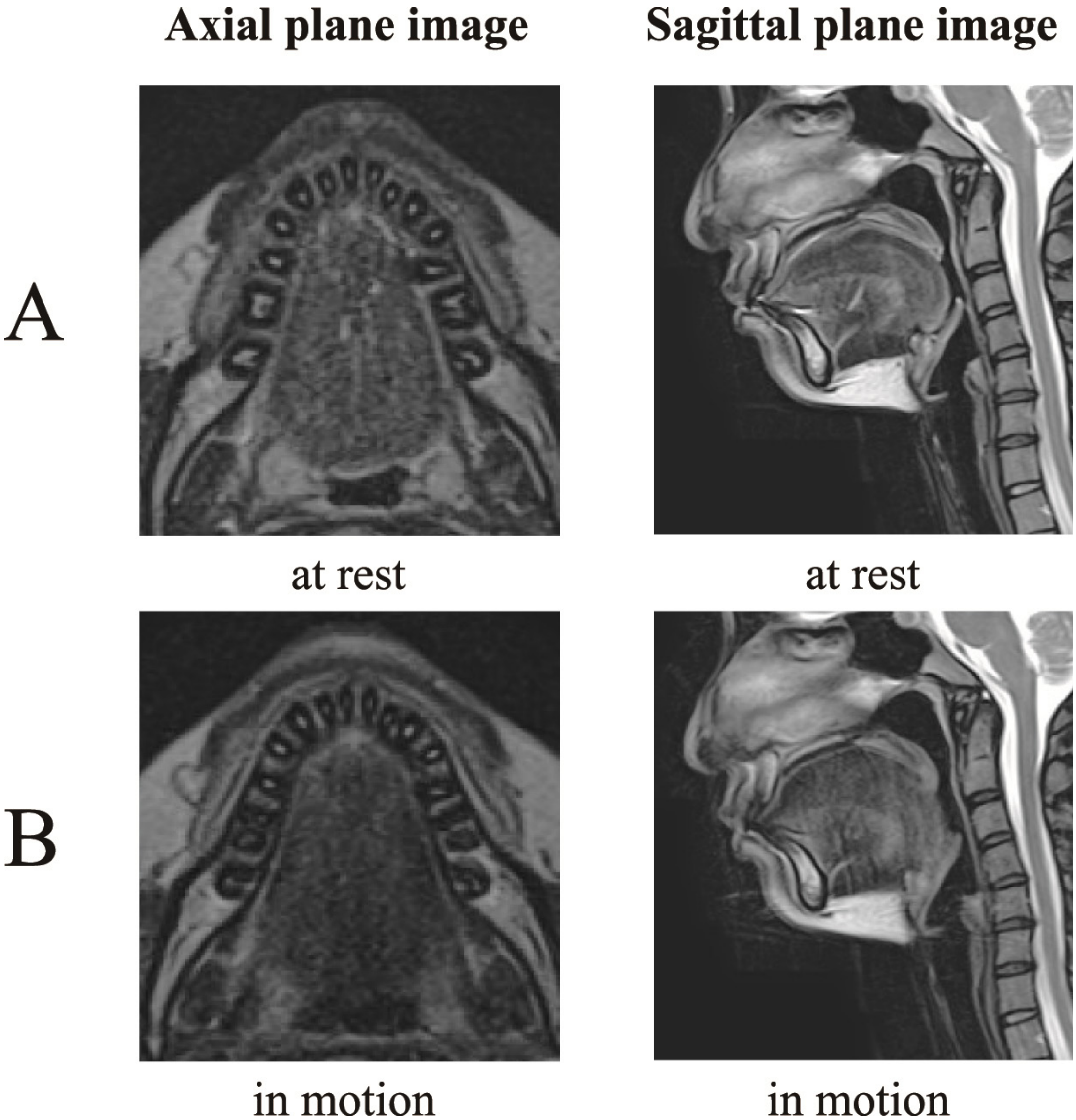

Fig. 4 MR image of the tongue at rest (A) and in motion (B)

Axial plane image with the tongue at rest: no obvious motion artifacts are recognized (A). Axial plane image with the tongue in motion: lack of image clarity in the run of the intrinsic muscle of tongue and the pharynx surrounding tissue caused by motion artifacts (B). Sagittal plane image with the tongue at rest: no obvious motion artifacts are observed (A). Sagittal plane image with the tongue in motion: lack of image clarity in the run of the genioglossus and the intrinsic muscles at the base of tongue (B).

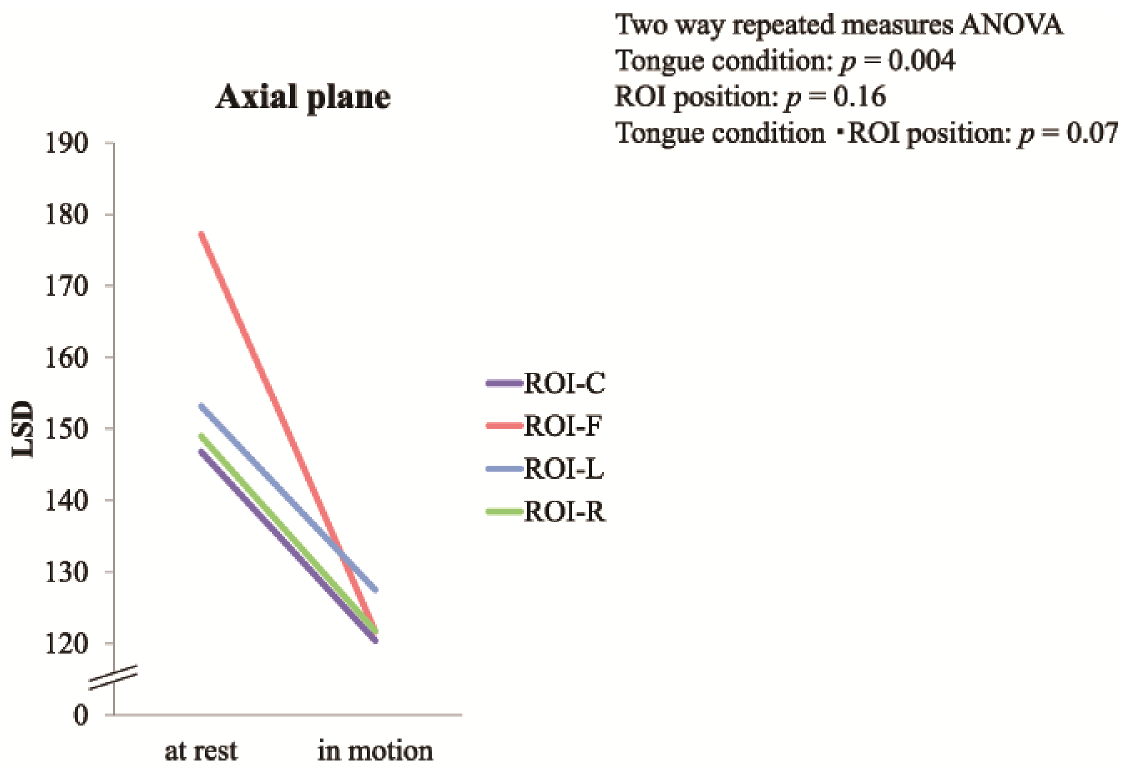

Fig.5　Comparison of the LSD between the tongue at rest and in motion in the axial plane image, with respective ROIs

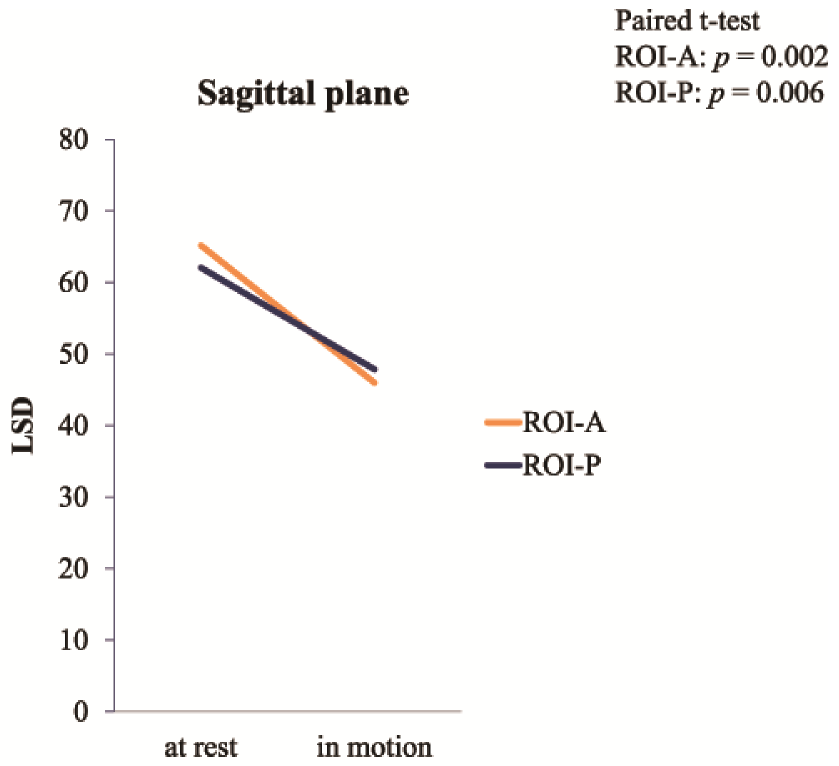

Fig. 6　Comparison of the LSD between the tongue at rest and in motion in the sagittal plane image, with respective ROIs

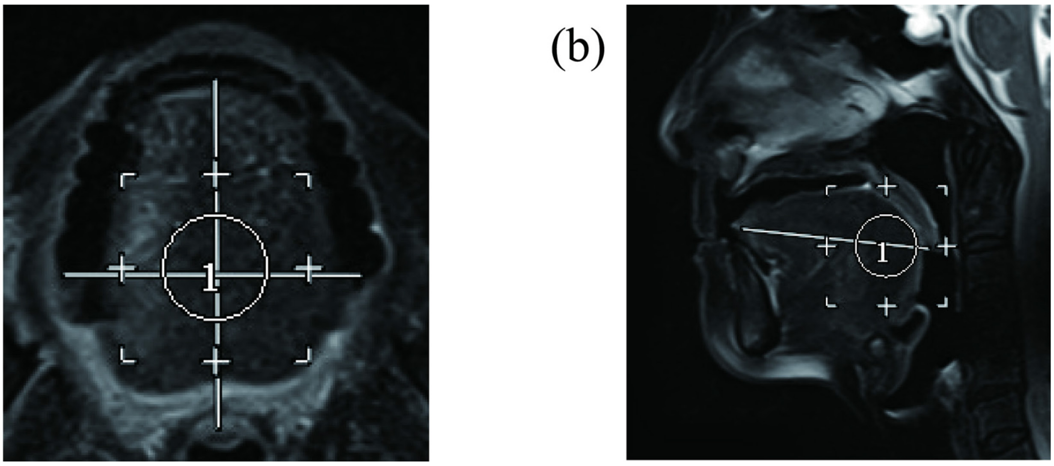

Fig. 7　Region of interest (ROI) determination

(a) The axial plane with a maximum tongue area. In imaging with DW, a circular ROI with a diameter of 20 mm was centered on the intersection of the midline and the line drawn to the maximum width of the tongue. The circle was plotted on the image of NDW and set as the ROI.

(b) The median sagittal plane. In imaging with DW, a circular ROI of 20 mm in diameter was centered on the line that linked the apex of tongue and the most posterior point of the soft palate, and in contact with tongue's posterior margins. The circle was plotted on the image of NDW and set as the ROI.

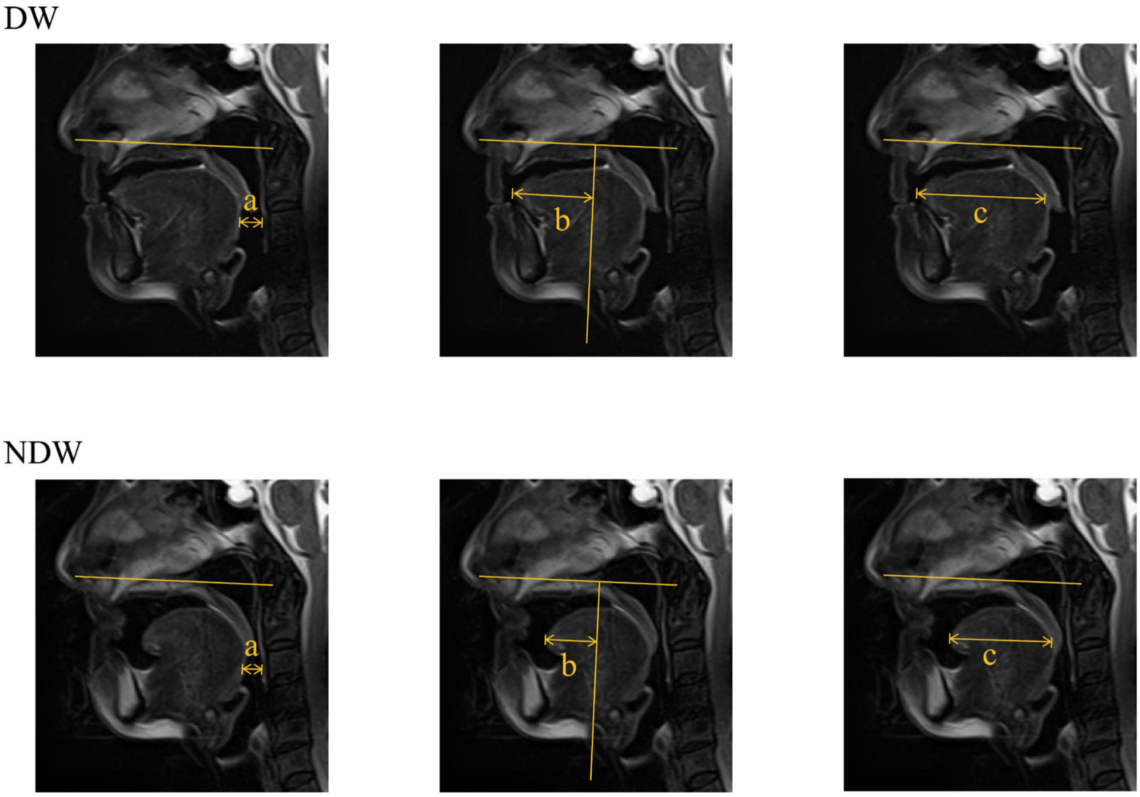

Fig. 8 Tongue form and position

Each form and position evaluation was performed by measuring the distance parallel to the palatal plane, which is an anatomical standard plane in the midsagittal slice, and is drawn based on a line from the anterior nasal spine to the posterior nasal spine (PNS).

(a) TB: the distance from the back wall of the pharynx to the tongue's posterior point.

(b) TA: the shortest distance from the line crossing at a right angle to the palatal plane through the PNS to the apex of tongue.

(c) TLD: The distance from the apex to the posterior point of tongue.

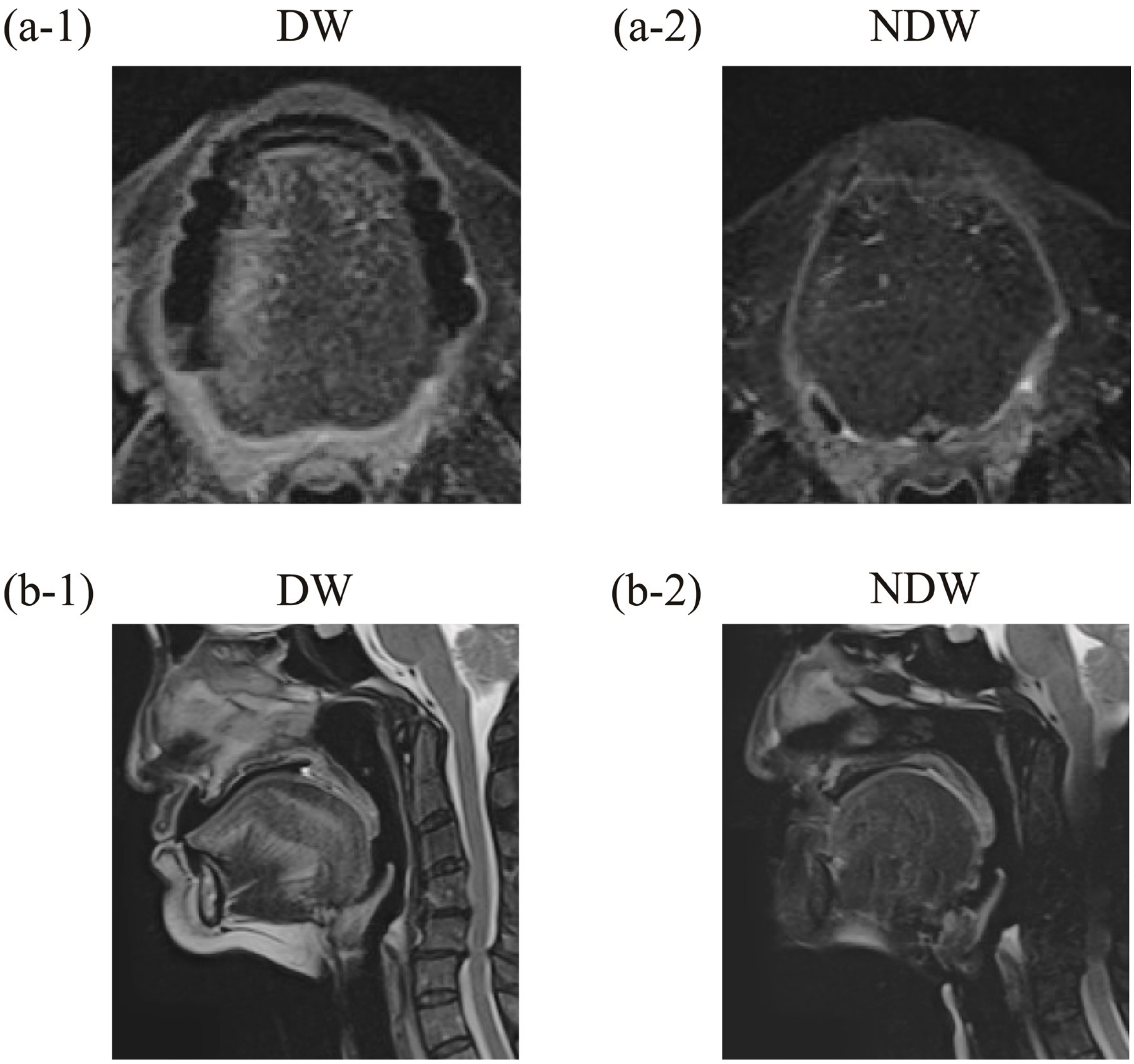

Fig. 9　Magnetic resonance imaging

a-1: DW/axial: the contour of the tongue and the running of the genioglossus muscle is clear.

a-2: NDW/axial: the TLD is shortened, and there is ambiguity of the tongue's anterior contour and the running of the genioglossus muscle.

b-1: DW/sagittal: no obvious motion artifacts. The contour of the tongue and the running of the genioglossus muscle are clear, as is the region of the superior longitudinal, inferior longitudinal, geniohyoid, and mylohyoid muscles.

b-2: NDW/sagittal: There is ambiguity in the running of the genioglossus muscle and the intrinsic muscle of the tongue, in addition to the contour of the tongue. The lips are recessed, and images of the mental and submandibular regions are unclear.

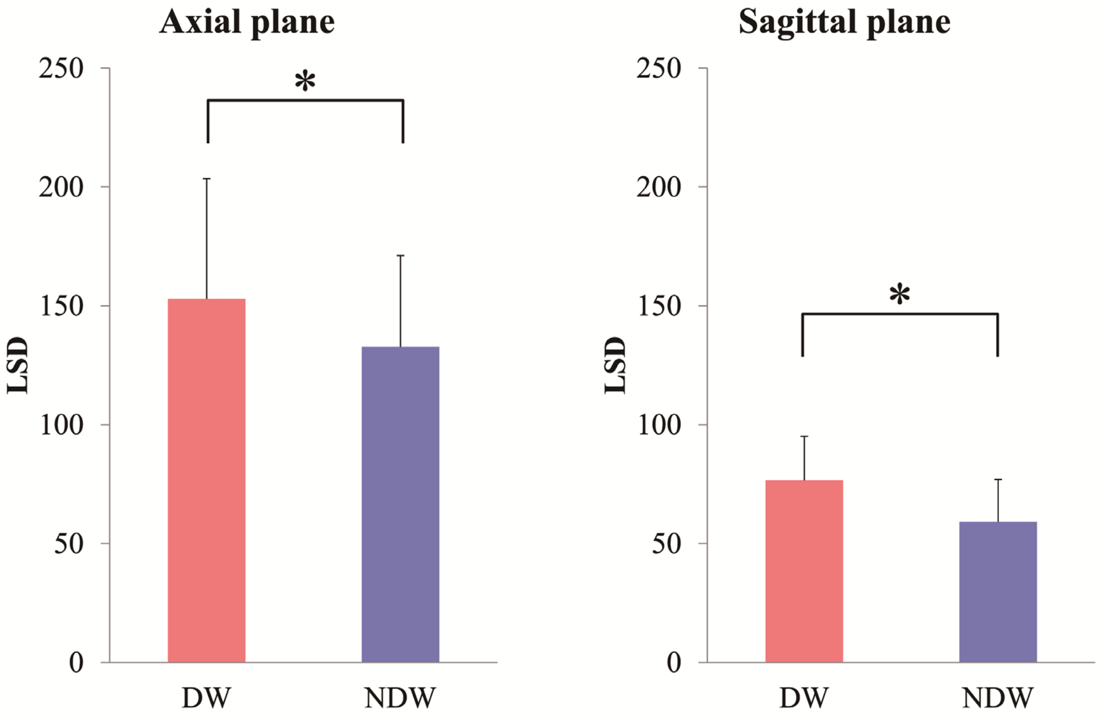

Fig. 10 Comparison of luminance standard deviation (LSD) between DW and NDW

In axial plane imaging, LSD was significantly greater with DW than NDW ($p = 0.047$). In sagittal plane imaging, LSD was significantly greater with DW than NDW ($p = 0.02$). *: $p < 0.05$.

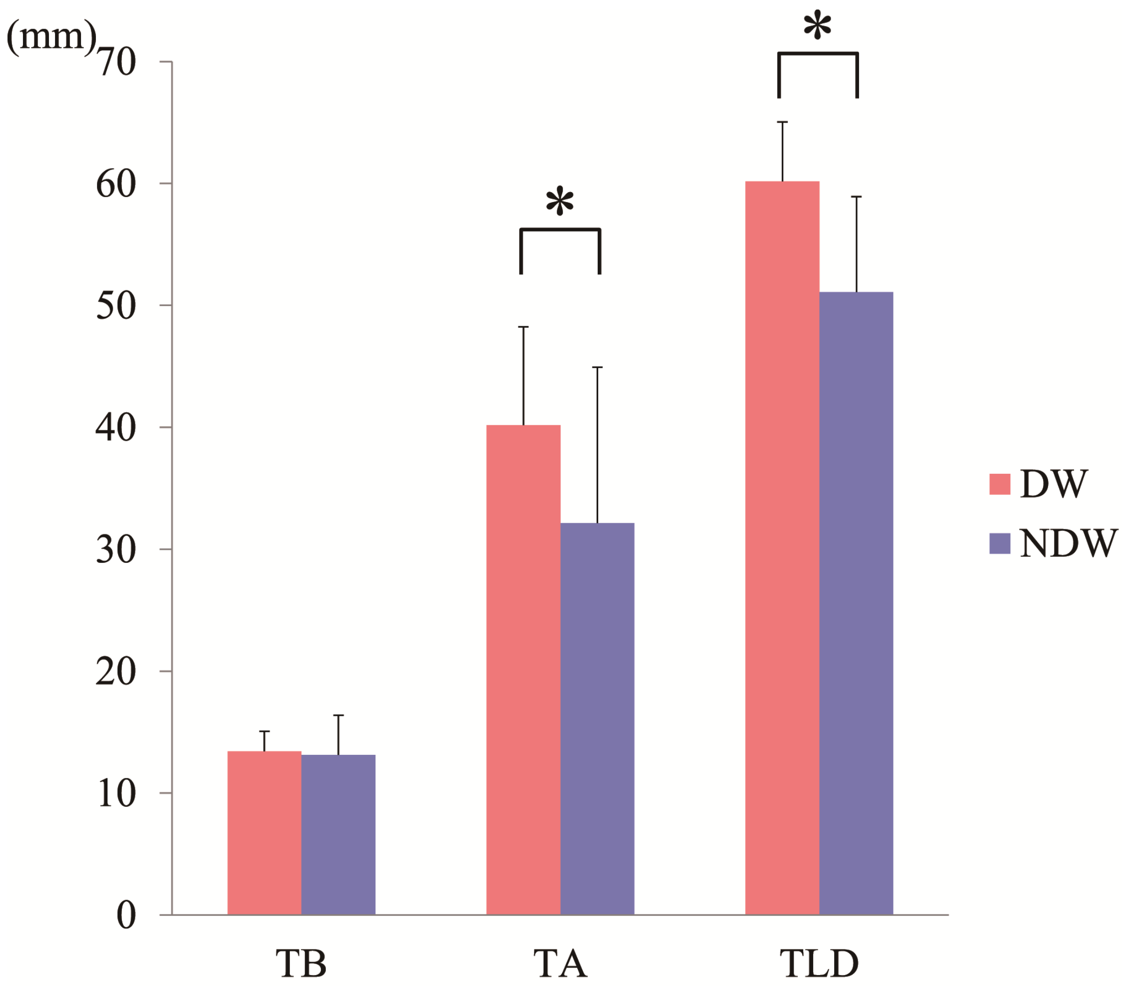

Fig. 11 Tongue form and position

In sagittal plane imaging, the distance from the back wall of the pharynx to the tongue's posterior end did not exhibit any significant differences between DW and NDW ($p = 0.78$). The shortest distance from the line crossing at a right angle to the palatal plane through the PNS to the apex of tongue was significantly greater with DW than NDW ($p = 0.007$). TLD was significantly greater with DW than NDW ($p = 0.001$). *: $p < 0.01$.